

# REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-01-

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any of this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (070 4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to provide information if it does not affect the operation of the Government. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

ig the  
ucing  
02-  
rrently

06661

not used

<b>1. REPORT DATE (DD-MM-YYYY)</b> 12-10-2001		<b>2. REPORT TYPE</b> Final		<b>3. DATES COVERED (From - To)</b> 04-15-98 to 10-14-01	
<b>4. TITLE AND SUBTITLE</b> BMDO-AASERT Group III Nitride Semiconductor nanostructure Research MOCVD Growth and Novel Characterizations of high Temperature, high carrier density and microcrack lasing Effects.				<b>5a. CONTRACT NUMBER</b> F49620-98-1-0431	
				<b>5b. GRANT NUMBER</b>	
				<b>5c. PROGRAM ELEMENT NUMBER</b>	
<b>6. AUTHOR(S)</b> Dr. Gil Han Park				<b>5d. PROJECT NUMBER</b>	
				<b>5e. TASK NUMBER</b>	
				<b>5f. WORK UNIT NUMBER</b>	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  Oklahoma State University Stillwater, OK 74078				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> AFOSR/NE AF Office of Scient. Research 110 Duncan Avenue, Rm. B115 Bolling AFB DC 20332-8050				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>	
<b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b>  DOD  AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (AFOSR) NOTICE OF TRANSMITTAL DTIC. THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLIC RELEASE. LAW AFR 100-12. DISTRIBUTION IS UNLIMITED.					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> This project provided training for graduate students in a wide variety of areas related to III-nitride research: epitaxial growth using MOCVD and MBE, optical and electrical characterization, post-growth processing and device fabrication. This training program was unique in that it exposed students to nearly all aspects of critical III-nitride technology through this comprehensive training.					
<b>15. SUBJECT TERMS</b> epitaxial growth, optical and electrical characterization, semiconductors					
<b>16. SECURITY CLASSIFICATION OF:</b> unclassified			<b>17. LIMITATION OF ABSTRACT</b>  UL	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b> J. W. Alexander
<b>a. REPORT</b> Unclassified	<b>b. ABSTRACT</b> Unclassified	<b>c. THIS PAGE</b> Unclassified			<b>19b. TELEPHONE NUMBER (include area code)</b> 405-744-6501

20020107 103

# **AFOSR – BMDO – AASERT Final Report**

**Contract # F49620-98-1-0431**  
**(April 15, 1998 to October 14, 2001)**

**“BMDO-AASERT Group III Nitride Semiconductor nanostructure research  
MOCVD Growth and Novel Characterizations of high Temperature, high carrier  
density and microcrack lasing effects”**

**December 10, 2001**

## ***Principal Investigator:***

**Dr. Jin-Joo Song**  
**Center for Laser and Photonics Research**  
**Department of Physics**  
**Oklahoma State University**  
**Stillwater, OK 74078**

## ***Report Prepared by:***

**Dr. Gil Han Park**  
**Research Scientist**  
**Oklahoma State University**  
**Stillwater, OK 74078**

## Table of Contents

Cover Page .....	1
Table of Contents .....	2
Summary .....	3
Students Supported .....	4
Student Theses: Abstracts .....	5
List of Publications .....	8
Conference Presentations .....	13

## Summary

This award provided training for several graduate students working in the laboratory of Dr. Jin-Joo Song in the Center for Laser and Photonics Research at Oklahoma State University, over the period 15 April 1998 - 14 October 2001. This award supported four graduate students; three of these completed their Ph.D. degrees and presented successful theses. One other left the laboratory and transferred to the laboratories of other OSU faculty in the College of Engineering.

The scientific training made possible through this award is evidenced by the progress described in detail in the publications outlined in this report. These publications were co-authored by one or more of the supported students during the period of the award. Difficulties with the construction and the bringing "on-line" of the MOCVD facilities at the OSU Clean Room required that most of the scientific experiments and analyses were performed on materials and devices grown and constructed by collaborators from other institutions (identified in the publications).

The delays with the Clean Room and MOCVD facilities have been previously described in a letter from the PI (Dr. Song) to Dr. Johnstone (18 April 2000). With reference to that letter, a second MOCVD unit has now been installed; stimulated emission and optical and electrical characterization of advanced nitride structures were performed; and femtosecond laser-induced carrier density experiments and theoretical analysis to interpret the carrier relaxation phenomena were carried out.

The attached data describes in detail the scientific work and the progress of the supported students.

## Students Supported

Student Name/ Grant Position	Degree (Ph.D, M.S., B.S.)	Date Supported by Grant	Graduation Date (if applicable)	Currently
Gordon H. Gainer/ Graduate Research Assistant	Ph.D., Physics	07-01-98 to 07-01-01	July 2001	Working in the laboratory of Dr. Jerzy Krasinski, Dept of Electrical & Computer Engineering, Oklahoma State University
Jack Biu Lam/ Graduate Research Assistant	Continuing Student	07-01-98 to 10-14-01	N/A	Transferred to Dr. Krasinski's laboratory
Brian D. Little/ Graduate Research Assistant	Ph.D., Physics	07-01-99 to 12-31-00	December 2000	Chicago, IL
Theodore Schmidt/ Graduate Research Assistant	Ph.D., Physics	07-01-98 to 12-31-98	December 1998	Unknown

Name: Gordon H. Gainer

Date of Degree: August, 2001

Institution: Oklahoma State University

Location: Stillwater, Oklahoma

Title of Study: EMISSION MECHANISMS OF InGaN-BASED III-NITRIDE  
HETEROSTRUCTURES

Pages in Study: 216

Candidate for the Degree of Doctor of Philosophy

Major Field: Physics

Scope and Method of Study: The emission mechanisms of InGaN-based III-nitride heterostructures were determined to aid in the design of InGaN-based light emitting diodes and laser diodes.  $\text{In}_{0.18}\text{Ga}_{0.82}\text{N}$  epilayers and  $\text{In}_{0.18}\text{Ga}_{0.82}\text{N}/\text{GaN}$  MQWs were studied by photoluminescence, photoluminescence excitation, time resolved photoluminescence, absorption, and stimulated emission. These measurements were performed as a function of excitation power density, excitation photon energy, excitation length, and temperature.

Findings and Conclusions: The photoluminescence peak energy had an "S-shaped" temperature dependence (redshift, blueshift, and then redshift with increasing temperature). Initially, with increasing temperature above 10 K, the charge carrier decay time increases, indicating the dominance of radiative recombination. This gives the carriers more opportunity to relax to lower energy band tail states before radiatively recombining, and this causes the initial redshift. With further temperature increases, the decay time decreases due to nonradiative processes, and this causes the blueshift. Then, with further temperature increases, the regular bandgap shrinkage causes a redshift, which is not as great as it would be without the band filling. The localized band tail states are caused by defects, such as In alloy inhomogeneity and layer thickness variations. These defects enhance the spontaneous and stimulated emission by localizing carriers and preventing them from migrating to nonradiative recombination centers. A mobility edge was found to be well above the spontaneous and stimulated peak positions, but much lower than the absorption edge, indicating that both the spontaneous and stimulated emissions originate from deep carrier localization. Carrier localization was also shown to be the spontaneous and stimulated emission mechanism by much more evidence, such as a strong correlation between the inverse stimulated emission threshold density and photoluminescence excitation spectra. Epitaxial lateral overgrowth was described as a method to greatly reduce the density of harmful defects, while keeping the relatively beneficial defects of bandgap inhomogeneity.

ADVISER'S APPROVAL: \_\_\_\_\_

Name: Brian Dean Little

Date of Degree: December, 2000

Institution: Oklahoma State University

Location: Stillwater, Oklahoma

Title of Study: OPTICAL PROPERTIES OF WIDE BANDGAP III-  
NITRIDE- AND ZINC OXIDE-BASED EPILAYERS,  
ALLOYS, AND HETEROSTRUCTURES

Pages in Study: 179

Candidate for the Degree of Doctor of Philosophy

Major Field: Physics

Scope and Method of Study: The optical properties of the III-Nitrides and ZnO were studied using a variety of spectroscopic experimental techniques. The semiconductor samples studied included epilayers, bulk crystals, alloys, and heterostructures. A large variety of picosecond and nanosecond laser systems as well as continuous wave light sources were used to optically excite the samples in this study. The sample emission was detected with photomultiplier tubes, CCD cameras, and optical multi-channel analyzers in conjunction with spectrometers.

Findings and Conclusions: The binding energy for intrinsic excitons in GaN was determined. The effect of strain on these excitons was studied. The optical properties of InGa<sub>N</sub> alloys were investigated. The characteristics of AlGa<sub>N</sub> and InGa<sub>N</sub> alloys as a function of pressure were studied. The dynamical behavior of photoexcited carriers in AlGa<sub>N</sub>/Ga<sub>N</sub> double heterostructures was explained. The stimulated emission from AlGa<sub>N</sub>/Ga<sub>N</sub> separate confinement heterostructures was studied as a function of the excitation wavelength. A comparison of the emission from highly-excited (In,Al)Ga<sub>N</sub> thin films and heterostructures was performed. The results obtained suggest that the group-III Nitrides and ZnO are excellent candidates for the development of ultraviolet optoelectronic devices. Several important optical parameters are provided, which are critical for understanding and designing efficient devices.

ADVISER'S APPROVAL: \_\_\_\_\_

Name: Theodore J. Schmidt

Date of Degree: December, 1998

Institution: Oklahoma State University

Location: Stillwater, Oklahoma

Title of Study: OPTICAL SPECTROSCOPY OF HIGHLY EXCITED GROUP III  
NITRIDES

Pages in Study: 235

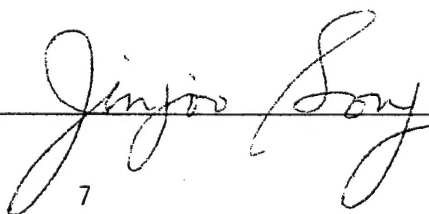
Candidate for the Degree of Doctor of Philosophy

Major Field: Physics

Scope and Method of Study: The optical properties of highly excited group III nitride semiconductors was studied. The research was undertaken to gain a better understanding of the optical phenomena associated with stimulated emission and lasing in this wide band gap semiconductor system. The optical properties of AlGa<sub>N</sub>, Ga<sub>N</sub>, InGa<sub>N</sub>, and their related heterostructures were monitored as the number of photo-generated free carriers was increased beyond that required to achieve population inversion. Experimental techniques used include: Optically pumped stimulated emission studies, variable-stripe gain spectroscopy, energy selective optical excitation spectroscopy, and nondegenerate optical pump-probe spectroscopy. Particular emphasis is placed on the optical properties of highly excited InGa<sub>N</sub>/Ga<sub>N</sub> multiple quantum well structures.

Findings and Conclusions: Stimulated emission and lasing was observed from all materials studied. Stimulated emission was observed at temperatures exceeding 700 K, indicating this material system is particularly well suited for high temperature opto-electronic applications. The mechanisms leading to optical gain in each material was ascertained as a function of temperature and optical excitation intensity. The stimulated emission characteristics of AlGa<sub>N</sub> were found to be similar to that of Ga<sub>N</sub>, while InGa<sub>N</sub> exhibited markedly different behavior. The results of nondegenerate optical pump-probe experiments indicate the group III nitrides are well suited for optical switching applications.

ADVISOR'S APPROVAL:



7



## Publications List

1. "Femtosecond pump-probe spectroscopy and time-resolved photoluminescence of an  $\text{In}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$  double heterostructure," C.K. Choi, B.D. Little, Y.H. Kwon, J.B. Lam and J.J. Song, *Physical Review B* **63**, 195302 (2001).
2. "Well-thickness dependence of emission from GaN/AlGaIn separate confinement heterostructures," G.H. Gainer, Y.H. Kwon, J.B. Lam, S. Bidnyk, A. Kalashyan, J.J. Song, S.C. Choi and G.M. Yang, *Applied Physics Letters* **78**, 3890 (2001).
3. "Optical properties and lasing in (In,Al)GaIn structures," S. Bidnyk, G.H. Gainer, S.K. Shee, J.B. Lam, B.D. Little, T. Sugahara, J. Krasinski, Y.H. Kwon, G.H. Park, S.J. Hwang, J.J. Song, G.E. Bulman, H.S. Kong, *Phys. Stat. Sol. (a)* **183**, 105 (2001).
4. "Linear and nonlinear optical properties of  $\text{In}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$  heterostructures," Y.H. Cho, T.J. Schmidt, S. Bidnyk, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra and S.P. DenBaars, *Physical Review B* **61**, 7571 (2000).
5. "Dynamics of anomalous optical transitions in  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  alloys," Y.H. Cho, G.H. Gainer, J.B. Lam, J.J. Song, W. Yang, W. Jhe, *Physical Review B* **61**, 7203 (2000).
6. "Time-resolved study of yellow and blue luminescence in Si- and Mg-doped GaN," Y.H. Kwon, S.K. Shee, G.H. Gainer, G.H. Park, S.J. Hwang and J.J. Song, *Applied Physics Letters* **76**, 840 (2000).
7. "Study of gain mechanisms in AlGaIn in the temperature range of 30-300 K," J.B. Lam, S. Bidnyk, G.H. Gainer, B.D. Little and J.J. Song, *Applied Physics Letters* **77**, 4101 (2000).
8. "MOCVD growth, stimulated emission and time-resolved PL studies of InGaIn/(In)GaIn MQWS: Well and barrier thickness dependence," S.K. Shee, Y. Kwon, J. Little, J.B. Lam, G.H. Gainer, G.H. Park, S.J. Hwang, J.J. Song, *Journal of Crystal Growth* **221**, 373 (2000).
9. "Comparative study of near-threshold gain mechanisms in GaIn epilayers and GaIn/AlGaIn separate confinement structures," S. Bidnyk, J.B. Lam, B.D. Little, G.H. Gainer, Y.H. Kwon, J.J. Song, *The International Society for Optical Engineering (SPIE) Conf. Proc.* **3947**, 126 (2000).
10. "Microcavity-based semiconductor lasers for near- and deep-UV applications," S. Bidnyk, J.B. Lam, B.D. Little, Y.H. Kwon, J.J. Song, G.E. Bulman, H.S. Kong, *Conference on Lasers and Electro-Optics (CLEO) 2000 Technical Digest, CMG5* (2000).
11. "GaIn/AlGaIn SCH UV semiconductor lasers: Effect of GaIn well thickness on lasing efficiency," G.H. Gainer, Y.H. Kwon, J.B. Lam, A. Kalashyan, J.J. Song, S.C. Choi, G.M. Yang, *Conference on Lasers and Electro-Optics (CLEO) 2000 Technical Digest, CMG4* (2000).
12. "A study of the structural and optical properties of  $\text{In}_x\text{Ga}_{1-x}\text{N}/\text{GaIn}$  quantum wells with different In compositions," Y.H. Kwon, G.H. Gainer, S. Bidnyk, Y.H. Cho, J.J. Song, M. Hansen, S.P. DenBaars, *Mat. Res. Soc. Symp. Proc.* **595**, MRS Internet J. Nitride Semicond. Res. **5S1**, W12.7 (2000).

13. "Dynamics of anomalous temperature-induced emission shift in MOCVD-grown (Al, In)GaN thin films," Y.H. Cho, G.H. Gainer, J.B. Lam, J.J. Song, W. Yang, W. Jhe, Mat. Res. Soc. Symp. Proc. **595**, MRS Internet J. Nitride Semicond. Res. **5S1**, W11.57 (2000).
14. "Microstructure-based lasing in GaN/AlGaIn separate confinement heterostructures," S. Bidnyk, J.B. Lam, B.D. Little, G.H. Gainer, Y.H. Kwon, J.J. Song, G.E. Bulman, H.S. Kong, Mat. Res. Soc. Symp. Proc. **595**, W11.22 (1999); MRS Internet J. Nitride Semicond. Res. **5S1**, W11.22 (2000).
15. "Structural and optical characteristics of  $\text{In}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$  multiple quantum wells with different In compositions," Y.H. Kwon, S. Bidnyk, J.J. Song, G.H. Gainer, Y. Cho, M. Hansen, Applied Physics Letters **75**, 2545 (1999).
16. "Near-threshold gain mechanisms in GaN thin films in the temperature range of 20 K to 700 K," S. Bidnyk, T. Schmidt, B.D. Little, J.J. Song, Applied Physics Letters **74**, 1 (1999).
17. "Optical properties of  $\text{In}_x\text{Ga}_{1-x}$  alloys grown by metalorganic chemical vapor deposition," W. Shan, W. Walukiewicz, E.E. Haller, B.D. Little, J.J. Song, M. McCluskey, N. Johnson, Z. Feng, M. Schurman, R. Stall, Journal of Applied Physics **84**, 4452 (1999).
18. "Stimulated emission in GaN thin films in the temperature range of 300 –700 K," S. Bidnyk, B.D. Little, T.J. Schmidt, Y.H. Cho, J. Krasinski, J.J. Song, B. Goldenberg, W. Yang, W.G. Perry, M.D. Bremser, R.F. Davis, Journal of Applied Physics **85**, 1792 (1999).
19. "A technique for evaluating optical confinement in GaN-based lasing structures," S. Bidnyk, B.D. Little, J.J. Song, Applied Physics Letters **75**, 15 (1999).
20. "Carrier dynamics of abnormal temperature-dependent emission shift in MOCVD-grown InGaIn epilayers and InGaIn/GaN quantum wells," Y.H. Cho, B.D. Little, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, MRS Internet J. Nitride Semicond. Res. **4S1**, G2.4 (1999).
21. "Room temperature laser action in laterally grown GaIn pyramids on (III) silicon," S. Bidnyk, B.D. Little, Y.H. Cho, J. Krasinski, J.J. Song, W. Yang, S.A. McPherson, MRS Internet J. Nitride Semicond. Res. **4S1**, G6.48 (1999).
22. "Mechanism of efficient ultraviolet lasing in GaIn/AlGaIn separate confinement heterostructures," S. Bidnyk, J.B. Lam, B.D. Little, Y.H. Kwon, J.J. Song, G.E. Bulman, H.S. Kong and T.J. Schmidt, Applied Physics Letters **75**, 3905 (1999).
23. "A comparison of the optical characteristics of AlGaIn, GaIn, and InGaIn thin films," Y.H. Cho, T.J. Schmidt, G.H. Gainer, J.B. Lam, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, W. Yang, D.S. Kim, W. Jhe, Phys. Stat. Sol. (b), **216**, 227 (1999).
24. "Effects of carrier localization on the optical characteristics of MOCVD-grown InGaIn/GaN heterostructures," Y.H. Cho, T.J. Schmidt, A.J. Fischer, S. Bidnyk, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, D.S. Kim, W. Jhe, Physica Status Solidi, submitted July 1999.
25. "Critical issues of localization in the development of InGaIn/GaN laser diodes," S. Bidnyk, Y.H. Cho, T.J. Schmidt, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars,

W.H. Jhe, Proceedings of Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, Technical Digest 2, 286 (1999).

26. "Comparison of spontaneous and stimulated emission from UV-blue photonic materials," B.D. Little, Y.H. Cho, T.J. Schmidt, G.H. Gainer, J.B. Lam, J.J. Song, W. Yang, S. Keller, U.K. Mishra, S.P. DenBaars, W. Jhe, Proceedings of Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, Technical Digest 2, 290 (1999).
27. "Novel technique for evaluation of optical confinement in semiconductor laser structures through spatially and spectrally resolved emission spectra," S. Bidnyk, T.J. Schmidt, B.D. Little, J. Krasinski, J.J. Song, Conference on Lasers and Electro-Optics (CLEO) 1999 Technical Digest, **CtuK52** (1999).
28. "Carrier recombination dynamics of  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  epilayers grown by MOCVD," Y.H. Cho, G.H. Gainer, J.B. Lam, J.J. Song, W. Yang, S.A. McPherson, Mat. Res. Soc. Symp. Proc. **572**, 457 (1999).
29. "Comparative study of emission from highly excited (In, Al)GaN thin films and heterostructures," B.D. Little, S. Bidnyk, T.J. Schmidt, J.B. Lam, Y.H. Kwon, J.J. Song, S. Keller, Y.K. Mishra, S. P. DenBaars, W. Yang, Mat. Res. Soc. Symp. Proc. **572**, 351 (1999).
30. "Optical confinement and gain mechanisms in GaN-based lasing structures," S. Bidnyk, T.J. Schmidt, B.D. Little, J.J. Song, 3<sup>rd</sup> Int. Conf. Nitride Semicond. Proc. (1999).
31. "Comparative study of near-threshold stimulated emission mechanism in GaN epilayers and InGaN/GaN multiquantum wells," S. Bidnyk, T.J. Schmidt, B.D. Little, J. Krasinski, J.J. Song, S. Keller, S.P. DenBaars, The International Society for Optical Engineering (SPIE) Conf. Proc. **3625**, 68 (1999).
32. "Ultrafast carrier dynamics in GaN epilayers studied by femtosecond pump-probe spectroscopy," A.J. Fischer, B.D. Little, T.J. Schmidt, C.K. Choi, J.J. Song, The International Society for Optical Engineering (SPIE) Conf. Proc. **3624**, 179 (1999).
33. "Time-resolved photoluminescence studies of GaN, InGaN, and AlGaIn grown by metalorganic chemical vapor deposition," Y.H. Cho, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, W. Yang, S.A. McPherson, The International Society for Optical Engineering (SPIE) Conf. proc. **3624**, 283 (1999).
34. "Femtosecond time-resolved absorption measurements in GaN epilayers under the conditions of strong optical pumping," A.J. Fischer, B.D. Little, T.J. Schmidt, J.J. Song, R. Horning, B.L. Goldenberg, The International Society for Optical Engineering (SPIE) Conf. Proc. **3624**, 179 (1999).
35. "Optical characteristics of group III nitride quantum structures," Y.H. Cho, W. Jhe, T.J. Schmidt, S. Bidnyk, G.H. Gainer, J.J. Song, Proceedings of the 3<sup>rd</sup> Korea-China Joint Workshop on Advance Materials (invited), 351 (1999).
36. "Comparison study of structural and optical properties of  $\text{In}_x\text{Ga}_{1-x}\text{N}$ /GaN quantum wells with different In compositions," Y.H. Kwon, G.H. Gainer, S. Bidnyk, Y.H. Cho, J.J. Song, M. Hansen, S.P. DenBaars, Mat. Res. Soc. Symp. Proc. (1999).

37. "Comparison of spontaneous and stimulated emission from UV-blue photonics materials," B.D. Little, Y.H. Cho, T.J. Schmidt, G.H. Gainer, J.B. Lam, J.J. Song, W. Yang, S. Keller, U.K. Mishra, S.P. DenBaars, W. Jhe, Conference on Laser and Electro-Optics, CLEO/Pacific Rim '99, Technical Digest 2, 290 (1999).
38. "Nonlinear optical spectroscopy of highly excited InGaN/GaN multiple quantum well blue laser structures," T.J. Schmidt, S. Bidnyk, Y.H. Cho, G.H. Gainer, J.J. Song, 1999 CLEO Technical Digest Series, Ctu4, 202 (1999).
39. "A novel technique to evaluation of optical confinement in semiconductor laser structures through spatially and spectrally resolved emission spectra," S. Bidnyk, T.J. Schmidt, B.D. Little, J. Krasinski, J.J. Song, 1999 CLEO Technical Digest Series, CtuK52, 145 (1999).
40. "Carrier recombination dynamics of  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  epilayers grown by MOCVD," Y.H. Cho, G. H. Gainer, J.B. Lam, J.J. Song, W. Yang, S.A. McPherson, Mat. Res. Soc. Symp. Proc., 572, 457 (1999).
41. "Optical characteristics of Group-III nitride quantum structures," Y.H. Cho, W. Jhe, T.J. Schmidt, S. Bidnyk, G.H. Gainer, J.J. Song, Proc. 3<sup>rd</sup> Korea-China Joint Workshop on Advanced Materials, 351 (1999).
42. "Comparative study of emission from highly excited (In,Al)GaN thin films and heterostructure," B.D. Little, S. Bidnyk, T.J. Schmidt, J.B. Lam, Y.H. Kwon, J.J. Song, S. Keller, Mat. Res. Soc. Symp. Proc. 572, 351 (1999).
43. "Study of near-threshold gain mechanisms in MOCVD-grown (In,Al)GaN epilayers and heterostructures," S. Bidnyk, T.J. Schmidt, B.D. Little, J.J. Song, Mat. Res. Soc. Symp. Proc. 572, 434 (1999).
44. "Intrinsic exciton transitions in GaN," W. Shan, A.J. Fischer, S.J. Hwang, B.D. Little, R. Hauenstein, X.C. Xie, J.J. Song, D. Kim, B. Goldenberg, R. Horning, S. Krishnankutty, W. Perry, M. Bremer, R. Davis, Journal of Applied Physics 83, 455 (1998)
45. "Laser action in GaN pyramids grown on (111) silicon by selective lateral overgrowth," S. Bidnyk, B.D. Little, Y. Cho, J. Krasinski, J.J. Song, W. Yang, S. McPherson, Applied Physics Letters 73, 2242 (1998).
46. "S-shaped temperature-dependent emission shift and carrier dynamics in InGaN/GaN multiple quantum wells," Y. Cho, G.H. Gainer, A. Fischer, J.J. Song, S. Keller, U. Mishra, S. DenBaars, Applied Physics Letters 73, 1370 (1998).
47. "Energy selective optically pumped stimulated emission from InGaN/GaN multiple quantum wells," T. Schmidt, G.H. Gainer, S. Keller, Y. Cho, J.J. Song, U. Mishra, Applied Physics Letters 73, 560 (1998).
48. "High-temperature stimulated emission in optically pumped InGaN/GaN multiquantum wells," S. Bidnyk, T.J. Schmidt, Y.H. Cho, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, Applied Physics Letters 72, 1623 (1998).

49. "Pump-probe spectroscopy of band tail states in metalorganic chemical vapor deposition grown InGaN," T.J. Schmidt, Y.H. Cho, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, Applied Physics Letters 73, 1892 (1998).
50. "High-temperature stimulated emission studies of MOCVD-grown GaN films," S. Bidnyk, B.D. Little, T.J. Schmidt, J. Krasinski and J.J. Song, SPIE 3419, 35 (1998).
51. "Near-band-edge photoluminescence emission in  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  under high pressure," W. Shan, J.W. Ager III, W. Waluiewicz, E.E. Haller, B.D. Little, J.J. Song, M. Schurman, Z.C. Feng, R.A. Stall, B. Goldenberg, Appl. Phys. Lett. 72, 2274 (1998).
52. "High-temperature stimulated emission in optically pumped InGaN/GaN multi-quantum wells," S. Bidnyk, T.J. Schmidt, Y.H. Cho, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, Appl. Phys. Lett. 72, 1623 (1998).

## **Conference Presentations**

1. "Optical properties and lasing in (In,Al)GaN-based structures," J.J. Song, S. Bidnyk, J.B. Lam, G.H. Gainer, and Y.H. Kwon, ISPA'2000 (invited).
2. "Study of gain mechanisms in  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  in the temperature range of 30 to 300 K," J.B. Lam, S. Bidnyk, G.H. Gainer, B.D. Little, J.J. Song, and W. Yang, CLEO'2000, CMG1, San Francisco, CA (May 7-12, 2000).
3. "Microcavity-based semiconductor lasers for near- and deep-UV applications," S. Bidnyk, J.B. Lam, B.D. Little, J.J. Song, G.E. Bulman, and H.S. Kong, CLEO'2000, CMG5, 78, San Francisco, CA (May 7-12, 2000).
4. "GaN/AlGaN SCH UV semiconductor lasers: Effect of GaN well thickness on lasing efficiency," G.H. Gainer, Y.H. Kwon, J.B. Lam, A. Kalashyan, J.J. Song, S.C. Choi and G.M. Yang, CLEO'2000, CMG4, San Francisco, CA (May 7-12, 2000).
5. "A comparative study of AlGaIn- and GaN-based lasing structures for near- and deep-UV applications," S. Bidnyk, J.B. Lam, B.D. Little, Y.H. Kwon, and J.J. Song, MRS Spring 2000, T3.8, (April 24-28, 2000).
6. "Comparative study of gain mechanisms in GaN epilayers and GaN/AlGaIn separate confinement heterostructures," S. Bidnyk, J.B. Lam, B.D. Little, G.H. Gainer, J.J. Song, APS March Meeting, R17.10, pp. 739-740, Minneapolis, MN (March 20-24, 2000).
7. "Study of stimulated emission in AlGaIn thin films in the temperature range of 30 K to 300 K," J.B. Lam, S. Bidnyk, G.H. Gainer, B.D. Little, J.J. Song, and W. Yang, APS March Meeting, R17.11, 740, Minneapolis, MN (March 20-24, 2000).
8. "Recent progress in the development of (Al, Ga)N lasing structures for near- and deep-ultraviolet emitters," S. Bidnyk, J.B. Lam, B.D. Little, and J.J. Song, Sixth Wide Bandgap III-Nitride Workshop, MP-1.4 (#23), Richmond, VA (March 12-15, 2000).
9. "Comparative study of near-threshold gain mechanisms in GaN epilayers and GaN/AlGaIn separate confinement heterostructures," S. Bidnyk, J.B. Lam, B.D. Little, G.H. Gainer, Y.H. Kwon, and J.J. Song, SPIE Photonics West, 3947-24, 126, San Jose, CA (January 23-28, 2000).
10. "Dynamics of anomalous temperature-induced emission shift in MOCVD-grown (Al, In)GaIn thin films," Y.H. Cho, G.H. Gainer, J.B. Lam, J.J. Song, W. Yang, and W. Jhe, MRS Fall 99, November 1999.
11. "Mechanism of efficient ultraviolet lasing in a GaN/AlGaIn separate confinement heterostructure," S. Bidnyk, J. B. Lam, B.D. Little, G.H. Gainer, Y.H. Kwon, J.J. Song, G.E. Bulman, and H.S. Kong, MRS Fall 99, November 1999.
12. "Comparison study of structural and optical properties of  $\text{In}_x\text{Ga}_{1-x}\text{N}$ /GaN quantum wells with different In compositions," Y.H. Kwon, G.H. Gainer, S. Bidnyk, Y.H. Cho, J.J. Song, M. Hansen, and S.P. DenBaars, MRS Fall 99, November 1999.



13. "Effects of carrier localization on the optical characteristics of MOCVD-grown InGaN/GaN heterostructures," Y.H. Cho, T.J. Schmidt, A.J. Fischer, S. Bidnyk, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, D.S. Kim, and W. Jhe, ICNS3, July 1999.
14. "A comparison of the optical characteristics of AlGaIn, GaN, and InGaIn thin films," Y.H. Cho, T.J. Schmidt, G.H. Gainer, J.B. Lam, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, W. Yang, D.S. Kim, and W. Jhe, ICNS3, July 1999.
15. "Optical nonlinearities in the band edge region of highly excited (Al, In)GaIn thin films studied via femtosecond and nanosecond optical pump-probe spectroscopy," T.J. Schmidt, A.J. Fischer, J.B. Lam, and J.J. Song, ICNS3, July 1999.
16. "Comparison of spontaneous and stimulated emission from UV-blue photonic materials," B.D. Little, Y.H. Cho, T.J. Schmidt, G.H. Gainer, J.B. Lam, J.J. Song, W. Yang, S. Keller, U.K. Mishra, S.P. DenBaars, and W. Jhe, Conference on Laser and Electro-Optics (CLEO)/Pacific Rim '99, July 1999.
17. "Critical issues of localization in the development of InGaIn/GaN laser diodes," S. Bidnyk, Y.H. Cho, T.J. Schmidt, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, and W. Jhe, Conference on Laser and Electro-Optics (CLEO)/Pacific Rim '99, July 1999.
18. "Comparative study of near-threshold stimulated emission mechanisms in GaIn epilayers and InGaIn/GaN multiquantum wells," S. Bidnyk, T.J. Schmidt, B.D. Little, J. Krasinski, J.J. Song, S. Keller, and S.P. DenBaars, SPIE Conf. Proc. Physics and Simulation of Optoelectronic Devices VII, 3625-8, pp. 68-77 (1999), SPIE Photonics West, San Jose, CA (January 25-29, 1999).
19. "Ultrafast carrier dynamics in GaIn epilayers studied by femtosecond pump-probe spectroscopy," A.J. Fischer, B.D. Little, T.J. Schmidt, C.K. Choi, and J.J. Song, SPIE Conf. Prod. Ultrafast Phenomena in Semiconductors 3624, pp. 179-187 (1999), SPIE Photonics West, San Jose, CA (January 25-29, 1999).

ASSERT Report

Grant # F49620-98-I-0431

“Group III-Nitride Semiconductor Nanostructure Research: MOCVD Growth and  
Novel Characterizations of High Temperature, High Carrier Density and  
Microcrack Lasing Effects”

September 1997-June 2001



Through this AASERT program, graduate students were trained in the area of material growth, optical and electrical investigations of wide gap III-nitride heterostructures. Students received training on experimental apparatus as shown in the following pages, including stimulated emission (SE), photorefectance (PR), photoluminescence excitation (PLE), and pump-probe experiments. The goal of the program was to study optical, electrical properties, epitaxial growth and photonic device applications. Blue and UV semiconductor lasers and optical modulators were of particular interest to us. During the course of the program, students actively collaborated with theoretical, MBE and MOCVD research groups from University of Illinois (Prof. Y. C. Chang) University of California at Santa Barbara (Prof. S. DenBaar), University of California at San Diego (Prof. C. Tu), Honeywell, University of North Carolina (Prof. R. F. Davis), EMCORE and CREE.

The students in our group hold many world records in important III-nitride research. These include:

- Highest temperature (700 K) lasing demonstration not only in GaN, but in any semiconductor.
- First demonstration of lasing in GaN.
- First demonstration of < 330 nm, AlGaIn UV stimulated emission.
- First clear elucidation of lasing mechanisms in separate confinement heterostructures (SCHs).
- First demonstration of well defined laser fringe modes associated with internal microcracks.
- First comparison between HVPE and MOCVD GaN stimulated emission thresholds.
- MOCVD growth and first systematic studies of barrier-width dependent stimulated emission in InGaIn/GaN multi-quantum-wells (MQWs).
- First femtosecond high carrier density pump-probe studies of GaN with an excitation wavelength significantly higher than the band edge.

Each subject above led to publications in reputable journals, and four invited book chapters were generated from the results. Additionally, students made numerous presentations at national and international conferences; the abstracts of refereed publication and conference presentations resulting from the AASERT award follow this report.

We firmly believe that our comprehensive and systematic growth and characterization work in III-nitrides will help understand the underlying mechanisms in lasing and hence help develop low threshold lasing structures which are more frequency agile. We have really picked up research momentum lately with progress in MOCVD growth, and consequently, there are many on-going projects which became active and effective due to this AASERT program.

Our original goals of this AASERT program has not been changed and we are still working on the very issues of GaN related materials and related devices such as:

- MOCVD growth of high quality nitride alloy quantum structures for efficient UV-visible light emitters, including laser diodes; MOCVD growth of n-type and p-type nitride samples for various device fabrication and spectroscopic studies, including DLTS.

- Stimulated emission and optical and electrical characterization studies of the advanced nitride structures grown on campus and also at collaborating laboratories.
- Development of prototype devices using our cleanroom processing facilities, including LEDs and detectors.

We installed much equipment for device fabrication, including sub-micron lithography, plasma enhanced chemical vapor deposition, and inductively coupled plasma - reactive ion etching. We also installed much state-of-the-art equipment for optical, structural, and electrical characterization. We finished testing and adjusting this equipment to make it fully operational. We have had initial success for InGaN/GaN MQW blue LEDs. We have grown GaN, InGaN, AlGaN and their heterostructures with the goal of optimizing laser diode structures. We grew series of InGaN/GaN MQWs to find the best well and barrier thicknesses, indium concentrations, growth interruption times, etc.

In addition to studying our samples we grew by MOCVD, we investigated samples grown by hydride vapor phase epitaxy (HVPE) by other research groups. Technologies and Devices, Inc. provided us with  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  structures grown by HVPE on sapphire and SiC substrates. Lincoln Laboratory sent us GaN grown by HVPE. We also worked with Eagle-Picher on the surface treatment of HVPE GaN.

Additional technical details can be found in the following documents.

- A. Publication List.
- B. Dr. Brian Little's Ph.D. Thesis
- C. Dr. Gordon Gainer's Ph.D Thesis

## RECENT PUBLICATIONS AND ABSTRACTS (1998-JUNE 2001)

### Publications (refereed):

"Femtosecond pump-probe spectroscopy and time-resolved photoluminescence of an InGaN/GaN double heterostructure," C. K. Choi, B. D. Little, Y. H. Kwon, J. B. Lam, J. J. Song, Y. C. Chang, S. Keller, U. K. Mishra, and S. P. DenBaars, *Phys. Rev. B* **63**, 195302 (2001).

"Time-resolved photoluminescence of InGaN/GaN multiple quantum well structures: effect of Si doping in the barriers," C. K. Choi, Y. H. Kwon, B. D. Little, G. H. Gainer, J. J. Song, Y. C. Chang, S. Keller, U. K. Mishra, and S. P. DenBaars, (submitted to *Phys. Rev. B* on 3/27/01).

"Ultrafast carrier dynamics in a highly excited GaN epilayer," C. K. Choi, Y. H. Kwon, J. S. Krasinski, G. H. Park, G. Setlur, J. J. Song, and Y. C. Chang, *Phys. Rev. B* **63**, 115315 (2001).

"MOCVD InGaN/GaN MQWs growth interruption effects," T. Sugahara, S. K. Shee, G. H. Park, S. J. Hwang, G. H. Gainer, J. J. Song, and S. Sakai, (submitted to *J. Cryst. Growth* on 3/22/01).

"Well thickness dependence of emission from GaN/AlGaIn separate confinement heterostructures," G. H. Gainer, Y. H. Kwon, J. B. Lam, S. Bidnyk, A. Kalashyan, J. J. Song, S. C. Choi and G. M. Yang, *Appl. Phys. Lett.* **78**, 3890 (2001).

"In<sub>2</sub>S<sub>3</sub> nanocolloids with excitonic emission: In<sub>2</sub>S<sub>3</sub> vs. CdS comparative study of optical and structural characteristics," D. K. Nagesha, X. Liang, A. A. Mamedov, G. Gainer, M. A. Eastman, M. Giersig, J. J. Song, T. Ni, N. A. Kotov, *The Journal of Physical Chemistry B* **105**, 7490 (2001).

"Optical properties and lasing in (In,Al)GaIn-based structures," S. Bidnyk, G. H. Gainer, S. K. Shee, J. B. Lam, B. D. Little, T. Sugahara, J. Krasinski, Y. H. Kwon, G. H. Park, S. J. Hwang, J. J. Song, G. E. Bulman, and H. S. Kong, *phys. stat. sol. (a)* **183**, 105 (2001).

"Comparative study of HVPE- and MOCVD-grown nitride structures for UV lasing application," J. B. Lam, G. H. Gainer, S. Bidnyk, Amal Elgawadi, G. H. Park, J. Krasinski, J. J. Song, D. V. Tsvetkov, and V. A. Dmitriev, *Mat. Res. Soc. Symp.* **639**, G6.4 (2001).

"Theoretical modeling of femtosecond pump-probe spectroscopy in GaIn systems," Y. C. Chang, C. K. Choi, and J. J. Song, *The International Society for Optical Engineering (SPIE) Conf. Proc., Ultrafast Phenomena in Semiconductors V*, **4280** 58 (2001).

"Femtosecond pump-probe spectroscopy of a highly excited GaIn epilayer," C. K. Choi, Y. H. Kwon, J. S. Krasinski, G. H. park, G. Setlur, J. J. Song, and Y. C. Chang, *The International Society for Optical Engineering (SPIE) Conf. Proc., Ultrafast Phenomena in Semiconductors V*, **4280** 89 (2001).

"Optical Properties of (Al)GaIn-Based Structures for Near- and Deep-Ultraviolet Emitters," S. Bidnyk, J. B. Lam, B. D. Little, G. H. Gainer, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong (submitted to *Jpn. J. Appl. Phys.* in 9/00).

"MOCVD growth, stimulated emission and time resolved PL studies of InGaN/(In)GaN MQWs: well and barrier thickness dependence," S. K. Shee, Y. H. Kwon, J. B. Lam, G. H. Gainer, G. H. Park, S. J. Hwang, B. D. Little, and J. J. Song, *J. Cryst. Growth* **221**, 373 (2000).

"Optical properties of (Al)GaN-based structures for near- and deep-ultraviolet emitters," S. Bidnyk, J. B. Lam, Y. H. Kwon, G. H. Gainer, B. D. Little, and J. J. Song, *Proc. Int. Workshop on Nitride Semiconductors (IWN2000)*, IPAP Conf. Series 1, 567 (2000).

"Linear and nonlinear optical properties of InGaN/GaN heterostructures," Y. H. Cho, T. J. Schmidt, S. Bidnyk, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, and S. P. DenBaars, *Phys. Rev. B* **61**, 7571 (2000).

"Dynamics of anomalous optical transition in  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  alloys," Y. H. Cho, G. H. Gainer, J. B. Lam, J. J. Song, *Phys. Rev. B* **61**, 7203 (2000).

"Study of gain mechanisms in AlGaIn in the temperature range of 30-300 K," J. B. Lam, S. Bidnyk, G. H. Gainer, B. D. Little, J. J. Song, and W. Yang, *Appl. Phys. Lett.* **77**, 4101 (2000).

"Time-resolved study of yellow and blue luminescence in Si- and Mg-doped GaN," Yong-Hwan Kwon, S. K. Shee, G. H. Gainer, G. H. Park, S. J. Hwang, and J. J. Song, *Appl. Phys. Lett.* **76**, 840 (2000).

"Study of gain mechanisms in  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  in the temperature range of 30 to 300 K," J. B. Lam, S. Bidnyk, G. H. Gainer, B. D. Little, J. J. Song, and W. Yang, *Conference on Lasers and Electro-Optics (CLEO) 2000 Technical Digest*, CMG1 (2000).

"Microcavity-based semiconductor lasers for near- and deep-UV applications," S. Bidnyk, J. B. Lam, B. D. Little, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong, *Conference on Lasers and Electro-Optics (CLEO) 2000 Technical Digest*, CMG5 (2000).

"GaN/AlGaIn SCH UV semiconductor lasers: Effect of GaN well thickness on lasing efficiency," G. H. Gainer, Y. H. Kwon, J. B. Lam, A. Kalashyan, J. J. Song, S. C. Choi, and G. M. Yang, *Conference on Lasers and Electro-Optics (CLEO) 2000 Technical Digest*, CMG4 (2000).

"A comparative study of AlGaIn and GaN-based lasing structures for near- and deep-UV applications," S. Bidnyk, J. B. Lam, G. H. Gainer, B. D. Little, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong, *Mat. Res. Soc. Symp. Proc.* T3.8, 316 (2000).

"Comparison study of structural and optical properties of  $\text{In}_x\text{Ga}_{1-x}\text{N}$ /GaN quantum wells with different In compositions," Y. H. Kwon, G. H. Gainer, S. Bidnyk, Y. H. Cho, J. J. Song, M. Hansen, and S. P. DenBaars, *Mat. Res. Soc. Symp. Proc.* **595** and *MRS Internet J. Nitride Semicond. Res.* **5S1**, W12.7 (2000).

"Dynamics of anomalous temperature-induced emission shift in MOCVD-grown (Al, In)GaIn thin films," Y. H. Cho, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, and W. Jhe, *Mat. Res. Soc. Symp. Proc.* **595** and *MRS Internet J. Nitride Semicond. Res.* **5S1**, W11.57 (2000).

"Microstructure-based lasing in GaN/AlGa<sub>N</sub> separate confinement heterostructures," S. Bidnyk, J. B. Lam, B. D. Little, G. H. Gainer, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong, *Mat. Res. Soc. Symp. Proc.* **595**, W11.22 (1999); *MRS Internet J. Nitride Semicond. Res.* **5S1**, W11.22 (2000).

"Comparative study of near-threshold gain mechanisms in GaN epilayers and GaN/AlGa<sub>N</sub> separate confinement heterostructures," S. Bidnyk, J. B. Lam, B. D. Little, G. H. Gainer, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong, *The International Society for Optical Engineering (SPIE) Conf. Proc.* **3947**, 126 (2000).

"Mechanism of efficient ultraviolet lasing in GaN/AlGa<sub>N</sub> separate confinement heterostructures," S. Bidnyk, J. B. Lam, B. D. Little, Y. H. Kwon, J. J. Song, G. E. Bulman, H. S. Kong, and T. J. Schmidt, *Appl. Phys. Lett.* **75**, 3905 (1999).

"Structural and optical characteristics of In<sub>x</sub>Ga<sub>1-x</sub>N/GaN multiple quantum wells with different In compositions," Y. H. Kwon, G. H. Gainer, S. Bidnyk, Y. H. Cho, J. J. Song, M. Hansen, and S. P. DenBaars, *Appl. Phys. Lett.* **75**, 2545 (1999).

"A technique for evaluating optical confinement in GaN-based lasing structures," S. Bidnyk, B. D. Little, J. J. Song, and T. C. Schmidt, *Appl. Phys. Lett.* **75**, 2163 (1999).

"Room-temperature deep-ultraviolet-stimulated emission from Al<sub>x</sub>Ga<sub>1-x</sub>N thin films grown on sapphire," T. J. Schmidt, Y. H. Cho, J. J. Song, and W. Yang, *Appl. Phys. Lett.* **74**, 245 (1999).

"Near-threshold gain mechanisms in GaN thin films in the temperature range of 20-700 K," S. Bidnyk, T. J. Schmidt, B. D. Little, and J. J. Song, *Appl. Phys. Lett.* **74**, 1 (1999).

"High resolution x-ray analysis of pseudomorphic InGa<sub>N</sub>/GaN multiple quantum wells: Influence of Si doping concentration," Y. H. Cho, F. Fedler, R. J. Hauenstein, G. H. Park, J. J. Song, S. Keller, U. K. Mishra, and S. P. DenBaars, *J. Appl. Phys.* **85**, 3006 (1999).

"Stimulated emission in GaN thin films in the temperature range of 300-700 K," S. Bidnyk, B. D. Little, T. J. Schmidt, Y. H. Cho, J. Krasinski, J. J. Song, B. Goldenberg, W. Yang, W. G. Perry, M. D. Bremser, and R. F. Davis, *J. Appl. Phys.* **85**, 1792 (1999).

"Critical issues of localization in the development of InGa<sub>N</sub>/GaN laser diodes," S. Bidnyk, Y.-H. Cho, T. J. Schmidt, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, W. Jhe, *Proceedings of Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, Technical Digest* **2**, 286 (1999).

"Comparison of spontaneous and stimulated emission from UV-blue photonic materials," B. D. Little, Y.-H. Cho, T. J. Schmidt, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, S. Keller, U. K. Mishra, S. P. DenBaars, W. Jhe, *Proceedings of Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, Technical Digest* **2**, 290 (1999).

"Optical emission characteristics of GaAs and GaN structures using low temperature near-field scanning optical spectroscopy," Y.-H. Cho, S. K. Eah, S. C. Hohng, D. S. Kim, G. M. Yang, J. J. Song, W. Jhe, *Proceedings of Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, Technical Digest* **3**, 999 (1999).

"Novel technique for evaluation of optical confinement in semiconductor laser structures through spatially and spectrally resolved emission spectra," S. Bidnyk, T. J. Schmidt, B. D. Little, J. Krasinski, J. J. Song, Conference on Lasers and Electro-Optics (CLEO) 1999 Technical Digest, CtuK52 (1999).

"Carrier recombination dynamics of  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  epilayers grown by MOCVD," Y. H. Cho, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, and S. A. McPherson, Mat. Res. Soc. Symp. Proc. **572**, 457 (1999).

"Nondegenerate optical pump-probe spectroscopy of highly excited group III nitrides," T. J. Schmidt, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Yang, Mat. Res. Soc. Symp. Proc. **572**, 433 (1999).

"Study of near-threshold gain mechanisms in MOCVD-grown GaN epilayers and InGaN/GaN heterostructures," S. Bidnyk, T. J. Schmidt, B. D. Little, J. J. Song, Mat. Res. Soc. Symp. Proc. **572**, 439 (1999).

"Comparative study of emission from highly excited (In, Al) GaN thin films and heterostructures," B. D. Little, S. Bidnyk, T. J. Schmidt, J. B. Lam, Y. H. Kwon, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Yang, Mat. Res. Soc. Symp. Proc. **572**, 351 (1999).

"Carrier dynamics of abnormal temperature-dependent emission shift in MOCVD-grown InGaN epilayers and InGaN/GaN quantum wells," Y. H. Cho, B. D. Little, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, and S. P. DenBaars, MRS Internet J. Nitride Semicond. Res. **4S1**, G2.4 (1999).

"Influence of Si-doping on carrier localization of MOCVD-grown InGaN/GaN multiple quantum wells," Y. H. Cho, T. J. Schmidt, S. Bidnyk, J. J. Song, S. Keller, U. K. Mishra, and S. P. DenBaars, MRS Internet J. Nitride Semicond. Res. **4S1**, G6.44 (1999).

"Room temperature laser action in laterally overgrown GaN pyramids on (111) silicon," S. Bidnyk, B. D. Little, Y. H. Cho, J. Krasinski, J. J. Song, W. Yang, and S. A. McPherson, MRS Internet J. Nitride Semicond. Res. **4S1**, G6.48 (1999).

"Amplification path length dependence studies of stimulated emission from optically pumped InGaN/GaN multiple quantum wells," T. J. Schmidt, S. Bidnyk, Y. H. Cho, A. J. Fischer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, MRS Internet J. Nitride Semicond. Res. **4S1**, G6.54 (1999).

"Laser action in optically pumped GaN pyramids grown on (111) silicon by selective lateral overgrowth," S. Bidnyk, B. D. Little, Y. H. Cho, J. Krasinski, J. J. Song, W. Yang, S. A. McPherson, MRS Internet J. Nitride Semicond. Res. **4S1**, G6.48 (1999).

"Optical confinement and gain mechanisms in GaN-based lasing structures," S. Bidnyk, T. J. Schmidt, B. D. Little, and J. J. Song, 3<sup>rd</sup> Int. Conf. Nitride Semicond. (ICNS3) Proc. (1999).

"Optical nonlinearities in the band edge region of highly excited (In)GaN thin films studied via femtosecond and nanosecond optical pump-probe spectroscopy," T. J. Schmidt, A. J. Fischer, and J. J. Song, phys. stat. sol. **216**, 505 (1999).

"Effects of carrier localization on the optical characteristics of MOCVD-grown InGa<sub>N</sub>/Ga<sub>N</sub> heterostructures," Y. H. Cho, T. J. Schmidt, A. J. Fischer, S. Bidnyk, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, D. S. Kim, and W. Jhe, *phys. stat. sol.* **216**, 181 (1999).

"A comparison of the optical characteristics of AlGa<sub>N</sub>, Ga<sub>N</sub>, and InGa<sub>N</sub> thin films," Y. H. Cho, T. J. Schmidt, G. H. Gainer, J. B. Lam, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, W. Yang, D. S. Kim, and W. Jhe, *phys. stat. sol.* **216**, 227 (1999).

"Evaluation of optical confinement in Ga<sub>N</sub>-based lasing structures," S. Bidnyk, T. J. Schmidt, and J. J. Song, *phys. stat. sol.* **216**, 517 (1999).

"Stimulated emission and pump-probe studies of wide-gap nitrides for UV-blue photonic applications," J. J. Song, S. Bidnyk, and T. J. Schmidt, *The International Society for Optical Engineering (SPIE) Conf. Proc.* **3986-04**, (1999).

"Comparative study of near-threshold stimulated emission mechanisms in Ga<sub>N</sub> epilayers and InGa<sub>N</sub>/Ga<sub>N</sub> multiquantum wells," S. Bidnyk, T. J. Schmidt, B. D. Little, J. Krasinski, J. J. Song, S. Keller, and S. P. DenBaars, *The International Society for Optical Engineering (SPIE) Conf. Proc.* **3625**, 68 (1999).

"Nonlinear optical spectroscopy of band tail states in highly excited InGa<sub>N</sub>," T. J. Schmidt, Y. H. Cho, S. Bidnyk, J. J. Song, S. Keller, U. K. Mishra, and S. P. DenBaars, *The International Society for Optical Engineering (SPIE) Conf. Proc.* **3625**, 57 (1999).

"Ultrafast carrier dynamics in Ga<sub>N</sub> epilayers studied by femtosecond pump-probe spectroscopy," A. J. Fischer, B. D. Little, T. J. Schmidt, C. K. Choi, J. J. Song, R. Horning, and B.L. Goldenberg, *The International Society for Optical Engineering (SPIE) Conf. Proc., Ultrafast Phenomena in Semiconductors III*, **3624**, 179 (1999).

"Time-resolved photoluminescence studies of Ga<sub>N</sub>, InGa<sub>N</sub>, and AlGa<sub>N</sub> grown by metalorganic chemical vapor deposition," Y. H. Cho, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, W. Yang, and S. A. McPherson, *The International Society for Optical Engineering (SPIE) Conf. Proc., Ultrafast Phenomena in Semiconductors III*, **3624**, 283 (1999).

"Optical characteristics of group III nitride quantum structures," Y. H. Cho, W. Jhe, T. J. Schmidt, S. Bidnyk, G. H. Gainer, and J. J. Song, *Proceedings of the 3<sup>rd</sup> Korea-China Joint Workshop on Advanced Materials*, (invited), 351 (1999).

"Stimulated emission and pump-probe studies of wide-gap nitrides for UV-blue photonics applications," J.J. Song, S. Bidnyk, and T.J. Schmidt, *ISPA '99 Conf.* Singapore, (Nov. 29-Dec. 3, 1999).

"Comparison of spontaneous and stimulated emission from UV-blue photonics materials," B.D. Little, Y.H. Cho, T.J. Schmidt, G.H. Gainer, J.B. Lam, J.J. Song, W. Yang, S. Keller, U.K. Mishra, S.P. DenBaars, and W. Jhe, *Conference on Laser and Electro-Optics, CLEO/Pacific Rim '99*, Technical Digest vol 2, 290 (1999).

"Optical Emission characteristics of GaAs and Ga<sub>N</sub> structures using low temperature near-field scanning optical spectroscopy," Y.H. Cho, S.K. Eah, S.C. Hohng, D.S. Kim,



G.M. Yang, J.J. Song, and W. Jhe, Conference on Laser and Electro-Optics, CLEO/Pacific Rim '99, Technical Digest vol 3, 999 (1999).

"Nonlinear optical spectroscopy of highly excited InGaN/GaN multiple quantum well blue laser structures," T.J. Schmidt, S. Bidnyk, Y.H. Cho, G.H. Gainer, J.J. Song, 1999 CLEO Technical Digest Series, CtuU4, 202 (1999).

"Novel technique for evaluation of optical confinement in semiconductor laser structures through spatially and spectrally resolved emission spectra," S. Bidnyk, T.J. Schmidt, B.D. Little, J. Krasinski, J.J. Song, 1999 CLEO Technical Digest Series, CtuK52, 145 (1999).

"Growth and in situ monitoring of GaN using IR interference effects," L. Considine, E.J. Thrush, J.A. Crawley, K. Jacobs, W. Van der Stricht, I. Moerman, P. Demeester, G.H. Park, S.J. Hwang, J.J. Song, J. Cryst. Growth **195**, 192 (1998).

"Optical properties of  $\text{In}_x\text{Ga}_{1-x}\text{N}$  alloys grown by metalorganic chemical vapor deposition," W. Shan, W. Walukiewicz, E.E. Haller, B.D. Little, J.J. Song, M.D. McCluskey, N.M. Johnson, Z.C. Feng, M. Schurman, and R.A. Stall, J. Appl. Phys. **84**, 4452 (1998).

"Pump-probe spectroscopy of band tail states in metalorganic chemical vapor deposition-grown InGaN," T.J. Schmidt, Y.H. Cho, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, Appl. Phys. Lett. **73**, 1892 (1998).

"Energy selective optically pumped stimulated emission from InGaN/GaN multiple quantum wells," T.J. Schmidt, Y.H. Cho, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, Appl. Phys. Lett. **73**, 560 (1998).

"S-shaped temperature-dependent emission shift and carrier dynamics in InGaN/GaN multiple quantum wells," Y.H. Cho, G.H. Gainer, A.J. Fischer, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, Appl. Phys. Lett. **73**, 1370 (1998).

"Excitation energy-dependent optical characteristics of InGaN/GaN multiple quantum wells," Y.H. Cho, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, Appl. Phys. Lett. **73**, 3181 (1998).

"Laser action in GaN pyramids grown on (111) silicon by selective lateral overgrowth," S. Bidnyk, B. Little, Y.H. Cho, J. Krasinski, J.J. Song, W. Yang, and S. A. McPherson, Appl. Phys. Lett. **73**, 2242 (1998).

"Stimulated emission characteristics of InGaN/GaN multiple quantum wells: Excitation length and excitation density dependence," T.J. Schmidt, S. Bidnyk, Y.H. Cho, A.J. Fisher, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, Appl. Phys. Lett. **73**, 3689 (1998).

"Influence of Si doping on characteristics of InGaN/GaN multiple quantum wells," Y.H. Cho, J.J. Song, S. Keller, M.S. Minsky, E. Hu, U.K. Mishra, and S.P. DenBaars, Appl. Phys. Lett. **73**, 1128 (1998).



- "Near-band-edge photoluminescence emission in  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  under high pressure," W. Shan, J.W. Ager III, W. Walukiewicz, E.E. Haller, B.D. Little, J.J. Song, M. Schurman, Z.C. Feng, R.A. Stall and B. Goldenberg, *Appl. Phys. Lett.* **72**, 2274 (1998).
- "High-temperature stimulated emission in optically pumped InGaN/GaN multi-quantum wells," S. Bidnyk, T.J. Schmidt, Y.H. Cho, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra and S.P. DenBaars, *Appl. Phys. Lett.* **72**, 1623 (1998).
- "Large optical nonlinearities near the band gap of GaN thin films," T.J. Schmidt, J.J. Song, Y.C. Chang, R. Horning and B. Goldenberg, *Appl. Phys. Lett.* **72**, 1504 (1998).
- "Intrinsic exciton transitions in GaN," W. Shan, A.J. Fischer, S.J. Hwang, B.D. Little, R.J. Hauenstein, X.C. Xie, J.J. Song, D.S. Kim, B. Goldenberg, R. Horning, S. Krishnankutty, W.G. Perry, M.D. Bremser and R.F. Davis, *J. Appl. Phys.* **83**, 455 (1998).
- "Characterization of InGaN/GaN lasing structures for high temperature device applications," S. Bidnyk, T.J. Schmidt, J.J. Song, S. Keller, U.K. Mishra, and S. P. DenBaars, *CLEO Technical Digest Series 6*, CWD2, 223-224 (1998).
- "Recombination dynamics in n- $\text{Al}_x\text{Ga}_{1-x}\text{As/n-In}_{0.5}\text{Ga}_{0.5}\text{P}$  type-II heterostructures," Yong-Hoon Cho, J.J. Song, H. Lim, Byung-Doo Choe, J.I. Lee, and D. Kim, *Appl. Phys. Lett.* **73**, 1245 (1998).
- "Amplification path length dependence studies of stimulated emission from optically pumped InGaN/GaN multiple quantum wells," T.J. Schmidt, S. Bidnyk, Y.H. Cho, A.J. Fischer, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, *Mat. Res. Soc. Symp.* **537**, G6.54 (1998).
- "Large optical nonlinearities in the bandgap region of GaN thin films grown by MOCVD on sapphire," T.J. Schmidt, J.J. Song, Y.C. Chang, *SPIE Proc.* **3419** 11 (1998).
- "Influence of Si-Doping on carrier localization of MOCVD-grown InGaN/GaN multiple quantum wells," Y.H. Cho, T.J. Schmidt, S. Bidnyk, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, *Mat. Res. Soc. Symp.* **537**, G6.44 (1998).
- "High-temperature stimulated emission studies of MOCVD-grown GaN films," S. Bidnyk, B.D. Little, T.J. Schmidt, J. Krasinski, J.J. Song, *SPIE Proc.* **3419**, 35 (1998).
- "Carrier dynamics of anti-Stokes photoluminescence in staggered-band lineup  $\text{Al}_x\text{Ga}_{1-x}\text{As-GaInP}_2$  heterostructures," Y.H. Cho, J.J. Song, D.S. Kim, H. Lim and B.D. Choe, *SPIE Proc.* **3277**, 134 (1998).
- "Study of stimulated emission in InGaN/GaN multi-quantum wells in the temperature range of 175 K to 575 K," S. Bidnyk, Y.H. Cho, T.J. Schmidt, J. Krasinski, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, *Mat. Res. Soc. Symp. Proc.* **512**, 199 (1998).
- "Optical characteristics of MOCVD-grown InGaN/GaN multiple quantum wells investigated by excitation energy dependent PL and PLE spectroscopy," Y.H. Cho, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, *Mat. Res. Soc. Symp. Proc.* **512**, 267 (1998).

“Large optical nonlinearities in the band gap region of GaN thin films grown by MOCVD on sapphire,” T.J. Schmidt, Y.C. Chang, and J.J. Song. SPIE **3419**, 61 (1998).

## Abstracts (1998- June 2001)

"Spatially resolved cathodoluminescence of laterally overgrown GaN pyramids on (111) Si substrate," Y. H. Cho, H.M. Kim, T.W. Kang, J.J. Song, and W. Yang, (accepted by the Fourth International Conference on Nitride Semiconductors).

"Femtosecond pump-probe spectroscopy of a highly excited GaN epilayer," C. K. Choi, Y. H. Kwon, J. S. Krasinski, G. H. Park, G. Setlur, J. J. Song, and Y. C. Chang, The International Society for Optical Engineering (SPIE) Photonics West 2001, 4280-10 (January 20-26, 2001).

"Theoretical modeling of femtosecond pump-probe spectroscopy in GaN systems," Y. C. Chang, C. K. Choi, and J. J. Song, The International Society for Optical Engineering (SPIE) Photonics West 2001, 4280-07 (January 20-26, 2001).

"Comparative study of HVPE- and MOCVD- grown laser structures for UV applications," J. B. Lam, S. Bidnyk, A. Elgawadi, G. H. Park, J. Krasinski, J. J. Song, D. V. Tsvetkov, V. A. Dmitriev, Mat. Res. Soc. Fall 2000, Boston, MA (November 27 - December 1, 2000).

"Optical properties and lasing in (In,Al)GaN-based structures," J. J. Song, S. Bidnyk, J. B. Lam, G. H. Gainer, and Y. H. Kwon, ISPSA 2000 (invited), Cheju, Korea (November 1 - 3, 2000).

"Absorption, emission, and carrier dynamics study of MOCVD-grown  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  Alloys," Y. H. Cho, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, and T. W. Kang, ISPSA 2000, Cheju, Korea (November 1 - 3, 2000).

"Optical properties and lasing in (In,Al)GaN-based structures," S. Bidnyk, J. B. Lam, Y. H. Kwon, G. H. Gainer, S. K. Shee, G. H. Park, S. J. Hwang, B. D. Little, and J. J. Song, International Workshop on Physics of Light-matter Coupling in Nitrides, France (October 8 - 12, 2000).

"Optical properties of (Al)GaN-based structures for near- and deep-ultraviolet emitters," S. Bidnyk, J. B. Lam, Y. H. Kwon, G. H. Gainer, B. D. Little, and J. J. Song, Int. Workshop on Nitride Semicond. (IWN2000), TA2-3, Nagoya, Japan (September 24 - 27, 2000).

"MOCVD growth, stimulated emission and time resolved PL studies of InGa $\text{N}/(\text{In})\text{Ga}\text{N}$  MQWs: well and barrier thickness dependence," S. K. Shee, Y. H. Kwon, J. B. Lam, G. H. Gainer, G. H. Park, S. J. Hwang, B. D. Little, J. J. Song, The Tenth International Conference on Metalorganic Vapor Phase Epitaxy (ICMOVPE-X), Sapporo, Japan (June 5 - June 9, 2000).

"Study of gain mechanisms in  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  in the temperature range of 30 to 300 K," J. B. Lam, S. Bidnyk, G. H. Gainer, B. C. Little, J. J. Song, and W. Yang, Conference on Lasers and Electro-Optics (CLEO) 2000, CMG1, 76, San Francisco, CA (May 7 - 12, 2000).

"Microcavity-based semiconductor lasers for near- and deep-UV applications," S. Bidnyk, J. B. Lam, B. D. Little, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong,

Conference on Lasers and Electro-Optics (CLEO) 2000, CMG5, 78, San Francisco, CA (May 7 - 12, 2000).

"GaN/AlGa<sub>N</sub> SCH UV semiconductor lasers: Effect of GaN well thickness on lasing efficiency," G. H. Gainer, Y. H. Kwon, J. B. Lam, A. Kalashyan, J. J. Song, S. C. Choi and G. M. Yang, Conference on Lasers and Electro-Optics (CLEO) 2000, CMG4, San Francisco, CA (May 7 - 12, 2000).

"A comparative study of AlGa<sub>N</sub>- and GaN-based lasing structures for near- and deep-UV applications," S. Bidnyk, J. B. Lam, B. D. Little, Y. H. Kwon, and J. J. Song, Mat. Res. Soc. Spring Meeting 2000, T3.8, 316, San Francisco, CA (April 24 - 28, 2000).

"Comparative study of gain mechanisms in GaN epilayers and GaN/AlGa<sub>N</sub> separate confinement heterostructures," S. Bidnyk, J. B. Lam, B. D. Little, G. Gainer, J. J. Song, American Physical Society March Meeting, R17.10, 739, Minneapolis, MN (March 20-24, 2000).

"Study of stimulated emission in AlGa<sub>N</sub> thin films in the temperature range of 30 K to 300 K," J. B. Lam, S. Bidnyk, G. Gainer, B. Little, J. J. Song, and W. Yang, American Physical Society March Meeting, R17.11, 740, Minneapolis, MN (March 20-24, 2000).

"Recent progress in the development of (Al, Ga)<sub>N</sub> lasing structures for near- and deep-ultraviolet emitters," S. Bidnyk, J. B. Lam, B. D. Little, and J. J. Song, Sixth Wide Bandgap III-Nitride Workshop, MP-1.4, Richmond, VA (March 12-15, 2000).

"Comparative study of near-threshold gain mechanisms in GaN epilayers and GaN/AlGa<sub>N</sub> separate confinement heterostructures," S. Bidnyk, J. B. Lam, B. D. Little, G. H. Gainer, Y. H. Kwon, and J. J. Song, The International Society for Optical Engineering (SPIE) Photonics West 2000, 3947-24, 126, San Jose, CA (January 23-28, 2000).

"Dynamics of anomalous temperature-induced emission shift in MOCVD-grown (Al, In)<sub>N</sub> thin films," Yong-Hoon Cho, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, and W. Jhe, Mat. Res. Soc. Fall 99, Boston, MA (November 29 - December 3, 1999).

"Mechanism of efficient ultraviolet lasing in a GaN/AlGa<sub>N</sub> separate confinement heterostructure," S. Bidnyk, J. B. Lam, B. D. Little, G. H. Gainer, Y. H. Kwon, J. J. Song, G. E. Bulman, and H. S. Kong, Mat. Res. Soc. Fall 99, Boston, MA (November 29 - December 3, 1999).

"Comparison study of structural and optical properties of In<sub>x</sub>Ga<sub>1-x</sub>N/GaN quantum wells with different In compositions," Yong-Hwan Kwon, G. H. Gainer, S. Bidnyk, Y. H. Cho, J. J. Song, M. Hansen, and S. P. DenBaars, Mat. Res. Soc. Fall 99, Boston, MA (November 29 - December 3, 1999).

"Stimulated emission and pump-probe studies of wide-gap nitrides for UV-blue photonic applications," (invited), J. J. Song, S. Bidnyk, and T. J. Schmidt, Design, 3896-04, Fabrication and Characterization of Photonic Devices, International Symposium on Photonics and Applications (ISPA), Singapore (November 29 - December 3, 1999).

"Optical characteristics of group III nitride quantum structures," (invited), Yong-Hoon Cho and W. Jhe (Center for Near-field Atom-photon Technology and Department of Physics, Seoul National University), T. J. Schmidt, S. Bidnyk, G. H. Gainer, and J. J. Song (Center for Laser and Photonics Research and Department of Physics, Oklahoma State University), 3<sup>rd</sup> Korea-China Joint Workshop on Advanced Materials, Cheju, Korea (August 23-27, 1999).

"Optical emission characteristics of GaAs and GaN based materials using near-field and far-field optics," (invited) Yong-Hoon Cho, Sang-Kee Eah, S. C. Hohng, D. S. Kim, W. Jhe (Seoul National University) T. J. Schmidt, S. Bidnyk, G. H. Gainer, and J. J. Song (Oklahoma State University), Korea Physics Society 99 Fall Meeting, I-05, Korea (October 15-16, 1999).

"Optical emission characteristics of GaAs and GaN structures using low temperature near-field scanning optical spectroscopy," Y.-H. Cho, S. K. Eah, S. C. Hohng, D. S. Kim, G. M. Yang, J. J. Song, W. Jhe, Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, P2.87, Seoul, Korea (August 30 - September 3, 1999).

"Femtosecond coherent and incoherent spectroscopies on GaN," Y. D. Jho, D. S. Kim, A. J. Fischer, J. J. Song, J. Kenrow, K. E. Sayed, and C. J. Stanton, Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, P1.53, Seoul, Korea (August 30 - September 3, 1999).

"Comparison of spontaneous and stimulated emission from UV-blue photonic materials," B. D. Little, Y.-H. Cho, T. J. Schmidt, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Jhe, Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, WP5, Seoul, Korea (August 30 - September 3, 1999).

"Critical issues of localization in the development of InGaN/GaN laser diodes," S. Bidnyk, Y.-H. Cho, T. J. Schmidt, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Jhe, Conference on Lasers and Electro-Optics (CLEO)/Pacific Rim '99, WP3, Seoul, Korea (August 30 - September 3, 1999).

"Optical confinement and gain mechanisms in GaN-based lasing structures," S. Bidnyk, T.J. Schmidt, B.D. Little, and J.J. Song, The Third International Conference on Nitride Semiconductors (ICNS3), We P092, 127, Montpellier, France (July 5-9, 1999).

"Effects of carrier localization on the optical characteristics of MOCVD-grown InGaN/GaN heterostructures," Y. H. Cho, T. J. Schmidt, A. J. Fischer, S. Bidnyk, G. H. Gainer, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, D. S. Kim, and W. Jhe, The Third International Conference on Nitride Semiconductors (ICNS3), We P093, Montpellier, France (July 5-9, 1999).

"A comparison of the optical characteristics of AlGaIn, GaN, and InGaIn thin films," Y. H. Cho, T. J. Schmidt, G. H. Gainer, J. B. Lam, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, W. Yang, D. S. Kim, and W. Jhe, The Third International Conference on Nitride Semiconductors (ICNS3), Montpellier, France (July 5-9, 1999).

"Optical nonlinearities in the band edge region of highly excited (Al, In)GaIn thin films studied via femtosecond and nanosecond optical pump-probe spectroscopy," T. J.

Schmidt, A. J. Fischer, J. B. Lam, and J. J. Song, The Third International Conference on Nitride Semiconductors (ICNS3), Montpellier, France (July 5-9, 1999).

"Evaluation of optical confinement in GaN-based lasing structures," S. Bidnyk, T. J. Schmidt, and J. J. Song, The Third International Conference on Nitride Semiconductors (ICNS3), Montpellier, France (July 5-9, 1999).

"Nondegenerate optical pump-probe spectroscopy of highly excited group III nitrides," T. J. Schmidt, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Yang, Mat. Res. Soc. Spring Meeting, San Francisco, CA (April 5-9, 1999).

"Carrier recombination dynamics of  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  epilayers grown by MOCVD," Y. H. Cho, G. H. Gainer, J. B. Lam, J. J. Song, W. Yang, and S. A. McPherson, Mat. Res. Soc. Spring Meeting, San Francisco, CA (April 5-9, 1999).

"Study of near-threshold gain mechanisms in MOCVD-grown GaN epilayers and InGaN/GaN heterostructures," S. Bidnyk, T. J. Schmidt, B. D. Little, J. J. Song, Mat. Res. Soc. Spring Meeting, Y5.37, 382, San Francisco, CA (April 5-9, 1999).

"Comparative study of emission from highly excited (In, Al) GaN thin films and heterostructures," B. D. Little, S. Bidnyk, T. J. Schmidt, J. B. Lam, Y. H. Kwon, J. J. Song, S. Keller, U. K. Mishra, S. P. DenBaars, and W. Yang, Mat. Res. Soc. Spring Meeting, Y7.4, 388, San Francisco, CA (April 5-9, 1999).

"Comparative study of near-threshold stimulated emission mechanisms in GaN epilayers and InGaN/GaN multiquantum wells," S. Bidnyk, T. J. Schmidt, B. D. Little, J. Krasinski, J. J. Song, S. Keller, and S. P. DenBaars, The International Society for Optical Engineering (SPIE) Photonics West 1999, 3625-8, San Jose, CA (January 25-29, 1999).

"Nonlinear optical spectroscopy of band tail states in highly excited InGaN," T. J. Schmidt, Y. H. Cho, S. Bidnyk, J. J. Song, S. Keller, U. K. Mishra, and S. P. DenBaars, The International Society for Optical Engineering (SPIE) Photonics West 1999, 3625-7, San Jose, CA (January 25-29, 1999).

"Time-resolved photoluminescence studies of GaN, InGaN, and AlGaIn grown by metalorganic chemical vapor deposition," Y.H. Cho, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, S.P. DenBaars, W. Yang, and S.A. McPherson, SPIE Proc., *Ultrafast Phenomena in Semiconductors III*, The International Society for Optical Engineering (SPIE) Photonics West 1999, 3624, San Jose, CA (January 25-29, 1999).

"Ultrafast carrier dynamics in GaN epilayers studied by femtosecond pump-probe spectroscopy," A. J. Fischer, B. D. Little, T. J. Schmidt, C. K. Choi, and J. J. Song, The International Society for Optical Engineering (SPIE) Photonics West 1999, 3624, San Jose, CA (January 25-29, 1999).

"Carrier dynamics of abnormal temperature-dependent emission shift in MOCVD-grown InGaIn epilayers and InGaIn/GaN quantum wells," Y.H. Cho, B.D. Little, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, Mat. Res. Soc. Symp. Proc. Fall (1998).

"Room temperature laser action in laterally overgrown GaN pyramids on (111) silicon," S. Bidnyk, B.D. Little, Y.H. Cho, J. Krasinski, J.J. Song, W. Yang, and S.A. McPherson, *Mat. Res. Soc. Symp. Proc.* Fall (1998).

"Stimulated emission studies of the group III nitrides over the temperature range 10 K to 700 K," S. Bidnyk, T.J. Schmidt, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, OSA Annual Meeting ILS-XIV: 14th Interdisciplinary Laser Science Conference (1998).

"Pump-probe spectroscopy of band tail states in MOCVD grown InGaN," T.J. Schmidt, Y.H. Cho, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, OSA Annual Meeting ILS-XIV: 14th Interdisciplinary Laser Science Conference (1998).

"Effect of Si doping on the optical properties of InGaN/GaN multiple quantum wells," Y.H. Cho, G. H. Gainer, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, OSA Annual Meeting ILS-XIV: 14th Interdisciplinary Laser Science Conference, Baltimore, Maryland (1998).

"High-temperature stimulated emission studies of MOCVD-grown GaN films," S. Bidnyk, C.K. Choi, T. Schmidt, J. Krasinski, and J.J. Song, *SPIE Photonics Taiwan '98* (1998).

"Large optical nonlinearities in the band gap region of GaN thin films grown by MOCVD on sapphire," T. Schmidt, J.J. Song, and Y.C. Chang, *SPIE Photonics Taiwan '98* (1998).

"Study of stimulated emission in GaN thin films in the temperature range of 20 K to 700 K," S. Bidnyk, C.K. Choi, T. J. Schmidt, J.K. Krasinski, and J.J. Song, *APS March Meeting*, **43**, 24 [A18.08] (1998).

"S-shaped temperature dependent emission shift and carrier dynamics in MOCVD-grown InGaN/GaN multiple quantum wells," Y.H. Cho, G.H. Gainer, A.J. Fischer, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, *APS March Meeting*, **43**, 87 [C18.05] (1998).

"Energy selective optically pumped blue stimulated emission in InGaN/GaN multiple quantum well structures," T.J. Schmidt, Y.H. Cho, J.K. Krasinski, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, *APS March Meeting*, **43**, 215 [G18.10] (1998).

"Optical characteristics of MOCVD-grown InGaN/GaN multiple quantum wells investigated by excitation energy dependent PL and PLE spectroscopy," Y.H. Cho, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, *MRS Spring Meeting* (1998).

"High-temperature stimulated emission in optically pumped InGaN/GaN multi-quantum wells," S. Bidnyk, Y.H. Cho, T.J. Schmidt, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, *MRS Spring Meeting* (1998).

"Characterization of InGaN/GaN lasing structures for high temperature device application," S. Bidnyk, Y.H. Cho, T.J. Schmidt, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBaars, *CLEO '98* (1998).

"Large optical nonlinearities near the band gap of MOCVD grown GaN thin films," T.J. Schmidt, J.J. Song, Y.C. Chang, R. Horning, and B. Goldenberg, *CLEO '98* (1998).

“Coherent dynamics of excitons in GaN studied by femtosecond four-wave-mixing spectroscopy,” A.J. Fischer, W. Shan, J.J. Song, D.S. Kim, and D.S. Yee, SPIE Photonics West '98 Conference, San Jose, CA (1998).

“Carrier dynamics of anti-Stokes photoluminescence in staggered band lineup AlGaAs-GaInP<sub>2</sub> heterostructures,” Y.H. Cho, J.J. Song, D.S. Kim, H. Lim, and D. Choe, SPIE Photonics West '98 Conference, San Jose, CA (1998).